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(54) STEEL FOR LOW STRAIN TYPE CARBURIZED AND QUENCHED GEAR

(57)Abstract:
PURPOSE: To stably produce a gear free from strain due to carburizing and quenching and excellent in dimensional accuracy by making the structure of a noncarburized part a dual phase structure consisting of ferrite and martensite, at the time of carburizing and quenching a gear made of a steel stock of specific composition to harden its surface.

CONSTITUTION: A gear is produced by using a steel slab which has a composition consisting of, by weight, 0.10-0.35% C, 1.0-2.50% Si, 0.20-1.50% Mn, 0.10-1.50% Cr, 0.01-0.50% Ni, 0.01-1.50% Mo, 0.01-0.10% Al, and the balance Fe or further containing specific small amounts of V, Ti, Nb, Zr, etc. Then, the gear is carburized and hardened, by which the surface of the gear is hardened. By this method, the superior gear, in which the Ac3 point parameter represented by equation 1 and the ideal critical diameter D1 represented by equation 2 are regulated to 850-950° C and 60-400mm, respectively, and the internal

structure of a noncarburized part is composed of a dual phase structure of martensite containing 10-70% ferrite and the non-carburized-and-quenched part in the inner part of the gear is composed of a dual phase structure of martensite containing 10-70% ferrite, can be produced.

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[Title of the Invention] STEEL FOR LOW STRAIN TYPE CURBURIZED AND QUENCH HARDENED GEARS

[Abstract]

[Constitution] Steel for low strain type carburized and quench hardened gears consisting of carbon C: 0.10 to 0.35wt.%, Si: 1.0 to 2.5wt.%, Mn: 0.20 to 1.50wt.%, Cr: 0.10 to 1.50wt.%, Ni: 0.01 to 0.50wt.%, Mo: 0.01 to 1.50wt.%, Al: 0.01 to 0.10wt.%, and the balance: Fe and inevitable impurities; having an Ac_3 point parameter within a range of 850 to 940°C; having an ideal critical diameter (D_1) within a range of 60 to 400 mm; and having the internal structure of a noncarburized area after carburizing and quench hardening composed of a dual phase structure of martensite containing 10 to 70% ferrite.

[Advantages] Steel for gears having about 50% less strain amount than that of a conventional steel as a result of a carburizing and quench hardening treatment and being excellent in a dedendum strength can be obtained in accordance with a usual carburizing and quench hardening treatment.

[Scopes of the Patent Claims]

[Claim 1] Steel for low strain type carburized and quench hardened gears, characterized by:

consisting of carbon (C) : 0.10 to 0.35wt.%
silicon (Si) : 1.0 to 2.50wt.%
manganese (Mn) : 0.20 to 1.50wt.%
chromium (Cr) : 0.10 to 1.50wt.%
nickel (Ni) : 0.01 to 0.50wt.%
molybdenum (Mo): 0.01 to 1.50wt.%
aluminum (Al) : 0.01 to 0.10wt.% and
the balance : iron (Fe) and inevitable impurities;

an Ac_3 point parameter calculated by the following equation (1) being within a range of 850 to 940°C,

$Ac_3 = 920 - 203\sqrt{C} + 44.7Si + 31.5Mo - 30Mn - 15.2Ni - 11Cr + 400Al$ ..... (1);

an ideal critical diameter (D_1) calculated by the following equation (2) being within a range of 60 to 400 mm,

$D_1 = 7.95\sqrt{C}\,(1 + 0.70Si)(1 + 3.3Mn)(1 + 2.16Cr)(1 + 0.36Ni)(1 + 3.00Mo)$ ..... (2); and

the internal structure of a noncarburized area after carburizing and quench hardening being composed of a dual phase structure of martensite containing 10 to 70% ferrite.

[Claim 2] The steel for low strain type carburized and quench hardened gears as claimed in Claim 1, comprising further at least one additional element selected from the following group consisting of:

vanadium (V): 0.01 to 0.50wt.%
titanium (Ti): 0.01 to 0.10wt.%
niobium (Ni): 0.01 to 0.10wt.% and
zirconium (Zr): 0.01 to 0.10wt.%.

[Detailed Description of the Invention]

[0001]

[Industrially Applicable Field] The present invention relates to steel for low strain type carburized and quench hardened gears having a very small amount of strain at the time of carburization and quench hardening, and used suitably for, e.g., a steel material of gears in automobiles, construction machineries, and industrial machineries and the like.

[0002]

[Prior Art] For instance, quietness in case of driving is remarkably improved in an up-to-date automobile. Noises in case of driving an automobile due to gear noises derive principally from gears. Gear noises are produced by problems in meshing of gears, and such problems in meshing of gears are derived from a strain produced in the case when a steel material for gears which has been molded into a predetermined shape is subjected to carburizing and quench hardening, or carbonitriding and quench hardening (hereinafter simply referred to as "carburizing and quench hardening") treatment in order to harden a surface of the resulting gear.

[0003] More specifically, since there occurs a transformation stress (a stress due to cubical expansion produced at the time when its internal structure is transformed from austenitic structure into martensite structure) due to a production of martensite in case of carburizing and quench hardening a steel material for gears, appearances of strain in the steel material are inevitable, so that dimensional accuracy of gears cannot be maintained at a high degree. Particularly, a transmission gear for automobiles is small, thin in its thickness, and the internal structure thereof is principally martensite containing partly bainite, so that strain appears easily in case of carburizing and quench

hardening the steel material, resulting in the most significant origin of gear noises, although there is a very severe restriction with respect to noises.

[0004] In order to improve dimensional accuracy of a gear, a profile modification treatment wherein a carburized layer is partly chipped off by machining may be applied to a steel material for gears which has been carburized and quench hardened to reduce a strain amount due to quench hardening. However, such profile modification by a machining operation results in an increase of manufacturing processes to decrease remarkably its productivity and to increase its manufacturing cost, besides there are unevenness in surface hardness and residual stress, whereby a problem arises from a viewpoint of quality of the product.

[0005] Because of the reasons as mentioned above, there are many cases where a steel material for gears is used without applying a profile modification treatment after carburizing and quench hardening. Accordingly, it is required to reduce a strain amount due to quench hardening for the sake of improving accuracy of a gear which has been carburized and quench hardened. Such strain amount due to quench hardening is influenced remarkably by hardenability of a raw material. Furthermore, since carburizing and quench hardening is usually implemented at a high temperature of about 920°C, it is considered that coarsening of austenite crystal grains during carburizing is one of causes for producing strain.

[0006] Heretofore, a variety of studies has been made on a means for reducing a strain amount due to quench hardening of a steel material for gears. For instance, a method for suppressing hardenability by controlling a composition of a chemical component of steel within a specified narrow range such that the hardenability is to be the lower limit of Jominy band, and a method for adjusting minutely crystal grains by allowing an element for reducing finely each size of crystal grains such as Al, Ti, and Nb to contain into steel (hereinafter referred to as "prior art 1") are known as disclosed in Japanese Patent Application Laid-Open Nos. 4-247848 and 59-123743.

[0007] Moreover, Japanese Patent Application Laid-Open No. 5-70925 discloses a method for maintaining a cog surface area in austenitic structure and making a cog inside area to be a fine ferrite-pearlitic structure by applying a carbonitriding treatment to a gear made of steel containing Si, Mn, Cr, Mo, V and the like within a specified range, thereafter cooling the resulting product to a temperature range equal to or less

than an Ar_1 transformation point in the cog surface area, i.e. a carbonitrided area, then maintaining again the product within a range of from a temperature equal to or more than an Ar_3 transformation point in the cog surface area, i.e. the carbonitrided area to a temperature equal to or less than the Ar_1 transformation point in the cog inside area (noncarburized area), and then quench hardening and tempering the product so treated (hereinafter referred to as "prior art 2").

[0008]

[The Problem to Be Solved by the Invention] The prior art 1 involves such a problem that there is a limitation to suppress occurrence of a strain accompanied with martensite transformation, so that the strain cannot sufficiently be reduced. On the other hand, the prior art 2 involves such a problem that since the cog inside area (noncarburized area) is a ferrite-pearlitic structure, it is difficult to assure a sufficient toughness, besides heat-treating operations therefor are complicated, so that not only its productivity is adversely affected, but also results in high production costs.

[0009] Accordingly, an object of the present invention is to solve the above-mentioned problems and to provide steel for a low strain type carburized and quench hardened gear which exhibits a very low appearance of a strain due to carburizing and quench hardening treatment, from which a gear having high dimensional accuracy can be obtained, and such gear generates scarcely noises in use, besides which is easily heat-treated, whereby it can be manufactured economically, so that it is suitably used for gears of, for example, automobiles, construction machineries, industrial machineries and the like.

[0010]

[Means for Solving the Problems] In view of the points mentioned above, the present inventors have studied eagerly for developing steel for a low strain type carburized and quench hardened gear from which a gear exhibiting a very scarce appearance of strain due to a carburizing and quench hardening treatment and having high dimensional accuracy can be obtained.

[0011] In view of the fact that a major cause by which a strain amount due to quench hardening is adversely affected is in a strain amount due to a cubical expansion which appears in the case where an austenitic structure transforms into a martensite structure, the present inventors have found that 10 to 70% of ferrite are mixed into an austenitic

structure at the time of heat treatment prior to quench hardening, whereby its structure after carburizing and quench hardening is made to be a dual phase structure of ferrite and martensite, so that a strain amount of quench hardening may be remarkably reduced.

[0012] In order to mix ferrite into an austenitic structure under a usual carburizing condition, it is necessary for elevating an Ac_3 transformation temperature. In this connection, influences upon the Ac_3 transformation temperature by Si, Mn, Cr, Mo, and V in steel have been studied in detail, and as a result, it has been found that when each content of these elements is adjusted, the dual phase structure of ferrite and martensite is easily obtained under such usual carburizing condition, and further a cog inside area (noncarburized area) is strengthened by ferrite-strengthening elements, whereby a strain amount of quench hardening can be remarkably reduced without deteriorating its fatigue strength.

[0013] The invention has been made on the basis of the above-described finding. Steel for low strain type carburized and quench hardened gears according to the invention is characterized by consisting of:

carbon (C) : 0.10 to 0.35wt.%
silicon (Si) : 1.0 to 2.50wt.%
manganese (Mn) : 0.20 to 1.50wt.%
chromium (Cr) : 0.10 to 1.50wt.%
nickel (Ni) : 0.01 to 0.50wt.%
molybdenum (Mo): 0.01 to 1.50wt.%
aluminum (Al) : 0.01 to 0.10wt.% and
the balance : iron (Fe) and inevitable impurities;

and further, if required, containing at least one element selected from the group consisting of:

vanadium (V): 0.01 to 0.50wt.%
titanium (Ti): 0.01 to 0.10wt.%
niobium (Ni): 0.01 to 0.10wt.% and
zirconium (Zr): 0.01 to 0.10wt.%;

an Ac_3 point parameter calculated by the following equation (1) being within a range of 850 to 940°C,

$Ac_3 = 920 - 203\sqrt{C} + 44.7Si + 31.5Mo - 30Mn - 15.2Ni - 11Cr + 400Al$ ..... (1);
an ideal critical diameter (D_1) calculated by the following equation (2) being within a range of 60 to 400 mm,
$D_1 = 7.95\sqrt{C}\,(1 + 0.70Si)(1 + 3.3Mn)(1 + 2.16Cr)(1 + 0.36Ni)(1 + 3.00Mo)$ ..... (2); and the internal structure of a noncarburized area after carburizing and quench hardening being composed of a dual phase structure of martensite containing 10 to 70% ferrite.

[0014]

[Function] According to the steel of the present invention, since each content of Si and Mo being elements for elevating an Ac_3 transformation temperature and improving hardenability is increased, the dual phase structure of ferrite and martensite is easily obtained by subjecting the steel to carburizing and quench hardening treatment. Accordingly, when ferrite absorbs expansion strain of martensite, a strain amount due to quench hardening decreases remarkably, and in addition, a hardness in a core section in case of quench hardening can be assured sufficiently, so that a fatigue strength by no means inferior to that of a conventional steel can be obtained.

[0015] In addition, there are many cases where a shot peening treatment is applied to gears used for automobiles for the sake of improvement of a fatigue strength. In this respect, since grain boundary oxidation layer decreases, so that no insufficient quench hardened structure is produced in the steel of the invention. Accordingly, even when shot peening treatment is applied to the steel of the invention, its surface coarseness does not deteriorate, so that its surface fatigue strength is elevated.

[0016] In the following, reasons for limiting each composition of chemical components of the steel for low strain type carburized and quench hardened gears of the invention to a value within the above-mentioned range will be described.

(1) Carbon (C): Carbon is an essential element necessary for assuring a core section strength due to carburizing and quench hardening, and accordingly, it is required to contain 0.10wt.% or more of carbon in order to achieve its function. However, when a carbon content exceeds 0.35wt.%, it results in deterioration in toughness and decrease in machinability. Thus, a carbon content should be restricted within a range of 0.10 to 0.35wt.%.

[0017] (2) Silicon (Si): Silicon is a comparatively inexpensive element being effective for elevating an Ac_3 transformation point. However, when a silicon content is less

than 1.00wt.%, a silicon concentration in the vicinity of a surface layer to be combined with very small amount of oxygen in a carburizing gas at the time of a carburizing treatment is low. As a result, the above-described very small amount of oxygen invades in the depths of the steel, whereby a grain boundary oxygen amount becomes remarkably deep, and thus it results in decrease of a fatigue strength. On the other hand, when a silicon content exceeds 2.50wt.% to be excessive, SiO_2-base inclusions increase. Hence, it results in decrease of a fatigue strength, on the contrary. For this reason, a silicon content should be limited within a range of 1.00 to 2.50wt.%.

[0018] (3) Manganese (Mn): Manganese is an element effective for improving hardenability and assuring a core section strength, and it is required to contain 0.20wt.% or more of manganese for achieving its function. However, since manganese has a function for lowering an Ac_3 transformation point, when a manganese content exceeds 1.50wt.% to be a large amount, not only no dual structure is obtained, but also its hardness becomes too high, resulting in deterioration of machinability. Accordingly, a manganese content should be limited within a range of 0.20 to 1.50wt.%.

[0019] (4) Chromium (Cr): Chromium is an element effective for improving hardenability as in the case of manganese, and it is required to contain 0.10wt.% or more of chromium for achieving its function. However, since chromium has the same function for lowering the Ac_3 transformation point as that of manganese, not only no dual phase structure is obtained, but also its hardness becomes too high, resulting in deterioration of machinability, when a chromium content exceeds 1.50wt.% to be a large amount. Accordingly, a manganese content should be restricted within a range of 0.10 to 1.50wt.%.

[0020] (5) Nickel (Ni): Nickel is an element effective for improving hardenability and toughness of steel, and it is required to contain 0.01wt.% or more of nickel for achieving its function. However, when a nickel content exceeds 0.50wt.% to be a large amount, its hardness becomes too high, so that its machinability deteriorates, and in addition, it is economically disadvantageous, because nickel is expensive. Accordingly, a nickel content should be limited within a range of 0.01 to 0.50wt.%.

[0021] (6) Molybdenum (Mo): Molybdenum is an element effective for elevating the Ac_3 transformation point and further improving hardenability, toughness, and fatigue strength of steel as in the case of nickel, and it is required to contain 0.01wt.% or more

of molybdenum for achieving its function. However, when a molybdenum content exceeds 1.50wt.%, its advantages are saturated, resulting in economical disadvantage. Accordingly, a molybdenum content should be restricted within a range of 0.01 to 1.50wt.%.

[0022] (7) Aluminum (Al): Aluminum is an element for producing AlN as a result of combination with nitrogen, functioning to make crystal grains into a minute state to reduce quench hardening strain, and in addition, effective for improving toughness and fatigue strength, and it is required to contain 0.01wt.% or more of aluminum for achieving its function. However, when an aluminum content exceeds 0.10wt.% to be a large amount, there arises a problem of increasing alumina-base inclusions. For this reason, an aluminum content should be restricted within a range of 0.01 to 0.10wt.%.

[0023] (8) Vanadium (V): Vanadium is an element effective for elevating hardenability and improving fatigue strength, and producing carbonitride to function for making crystal grains into a minute state to reduce quench hardening strain. In this respect, it is required to contain 0.01wt.% or more of vanadium for achieving its function. However, when a vanadium content exceeds 0.50wt.%, its advantages are saturated, resulting in economical disadvantage. Accordingly, a vanadium content should be restricted within a range of 0.01 to 0.50wt.%.

[0024] (9) Titanium (Ti), Niobium (Nb), Zirconium (Zr): Titanium, niobium, and zirconium are elements each effective for making austenite crystal grains into a minute state, and having a function for elevating yield strengths of a carburized area and the inside of the resulting steel to contribute an improvement of a fatigue strength. Accordingly, if needed, at least one element of those described above is allowed to contain in steel to be treated. In this respect, however, when a content of at least one member of titanium, niobium, and zirconium is less than 0.01wt.%, the above-mentioned function cannot be obtained. On the other hand, when a content of at least one element of those described above exceeds 0.10wt.%, its advantage is saturated, resulting in economical disadvantage. Accordingly, a content of at least one of titanium, niobium, and zirconium should be limited within a range of 0.01 to 0.10wt.%.

[0025] Impurities of P, S, Cu and the like other than those mentioned above may be contained in steel of the present invention. Furthermore, free-machining elements such as S, Pb, Ca, and Se may be contained, if needed, in order to elevate machinability

of the steel.

[0026] (10) Ac_3 transformation point parameter: When an Ac_3 transformation point parameter calculated by the following equation (1) is less than 850°C, an existence of ferrite cannot be assured in austenite, even if the steel is maintained at a carburizing temperature. On the other hand, when the Ac_3 transformation point parameter exceeds 940°C, a ferrite amount becomes excessive, whereby a strength in the core section becomes insufficient. Accordingly, the Ac_3 transformation point parameter calculated by the following equation (1) should be restricted within a range of 850 to 940°C:

$Ac_3 = 920 - 203\sqrt{C} + 44.7Si + 31.5Mo - 30Mn - 15.2Ni - 11Cr + 400Al$ ..... (1).

[0027] (11) Ideal critical diameter (D_1): An ideal critical diameter (D_1) is a value indicating hardenability of steel, and it is required that a value of the ideal critical diameter (D_1) calculated by the following equation (2) is 60 mm or more as austenite grain size No. 8 in order to assure a desired fatigue strength. On the other hand, when the above-described value (D_1) exceeds 400 mm, effects of ferrite existing mixedly in an austenite structure disappear, so that a hardening strain amount becomes large. Accordingly, the ideal critical diameter (D_1) calculated by the following equation (2) as the austenite grain size No. 8 should be restricted within a range of 60 to 400 mm:

$D_1 = 7.95\sqrt{C}\,(1 + 0.70Si)(1 + 3.3Mn)(1 + 2.16Cr)(1 + 0.36Ni)(1 + 3.00Mo)$ ..... (2).

[0028] (12) Ferrite amount of internal structure (noncarburized area): When a ferrite amount of internal structure (noncarburized area) is less than 10%, a transformation strain of martensite cannot be absorbed sufficiently, whereby a quench hardening strain cannot be suppressed in a small amount. On the other hand, when the above-described ferrite amount exceeds 70%, it becomes difficult to maintain a desired strength and toughness. Accordingly, a ferrite amount of the internal structure (noncarburized area) should be limited within a range of 10 to 70%.

[0029]

[Examples] In the following, the invention will be described in comparison of comparative examples to the examples of the invention wherein slabs are prepared from steels Nos. 1 to 3 of the invention each having a composition of chemical components, an Ac_3 transformation point parameter, and an ideal critical diameter (D_1) within a specified range of the invention, conventional steels Nos. 1 to 3 and comparative steels Nos. 4 and 5 each of which has at least one factor of the composition of chemical

components, the Ac_3 transformation point parameter, and the ideal critical diameter (D_1) being in out of the range specified by the present invention, respectively, and as shown in Table 1.

[0030]

[Table 1]

No.		Composition of Chemical Components (wt.%)								Ac_3 Point Parameter	D_1 Value (mm)
		C	Si	Mn	Ni	Cr	Mo	Al	The Other		
The Present Invention Steel	1	0.20	1.44	0.70	0.05	0.50	0.77	0.029	-	902	167
	2	0.13	2.40	0.27	0.04	1.45	0.03	0.012	Nb: 0.03	935	67
	3	0.33	1.05	1.45	0.15	0.80	0.60	0.098	V: 0.19	854	372
	4	0.21	1.43	0.68	0.25	0.51	1.43	0.025	Ti: 0.08 Nb: 0.09	916	288
	5	0.21	1.40	0.68	0.49	0.13	0.75	0.24	Zr: 0.04	894	115
	6	0.21	1.41	1.45	0.05	0.50	0.03	0.025	-	851	97
Conventional Steel	1	0.21	0.24	1.44	0.05	0.51	0.03	0.025	-	799	58
	2	0.20	0.21	0.84	0.05	1.16	0.02	0.019	-	808	59
	3	0.22	0.21	0.76	0.05	1.11	0.16	0.019	-	811	77
Comparative Steel	4	0.21	1.45	1.49	0.06	1.53	0.77	0.025	-	864	637
	5	0.15	2.60	1.02	0.16	0.68	0.35	0.045	-	946	204

[0031] The conventional steels No. 1 to 3 correspond to conventional JIS steel types wherein the conventional steel No. 1 corresponds to JIS SMnC420, the conventional steel No. 2 corresponds to JIS SCr420, and the conventional steel No. 3 corresponds to JIS SCM420, and any of them has a Si content and an Ac_3 transformation point parameter being out of the range specified by the invention to be a small value. Moreover, a D_1 value of the conventional steels Nos. 1 and 2 is out of the range specified by the invention to be a small value. Furthermore, the comparative steel No. 4 is steel having a D_1 value higher than that of the specified range of the present invention, and the comparative steel No. 5 is steel having an Ac_3 transformation point parameter more than that of the specified range of the invention.

[0032] Each of slabs made from the above-described present invention steels, conventional steels, and comparative steels is hot-rolled, then forged to prepare a rod steel having 20 to 90 mm diameter, the resulting rod steel is normalized, and then worked into a quench hardening test piece and a fatigue test piece, respectively. Thereafter, the test pieces thus obtained are subjected to carburizing and quench hardening treatment, and further tempering treatment. Then, a carburized and quench hardened strain amount, rotary bending fatigue properties, and gear fatigue properties are examined in accordance with the following manners.

[0033] (1) Carburized and quench hardened strain amount: A disk-shaped navy C test pieces 1 having an opening 2 and a circular space 3 shown in FIG. 1 of a front view and FIG. 2 of a side view are prepared from a rod steel having 65 mm diameter. A dimension of each section of the test piece 1 is as follows:

Diameter of test piece (a): 60 mm, thickness (b): 12 mm, diameter of circular space (c): 34.8 mm, opening dimension (d): 6 mm.

[0034] Ten pieces of navy C test pieces 1 each having the above-described shape are prepared per each of the steels. A rate of change in the opening 2 occurred in the case where a test piece 1 is subjected to a carburizing treatment under the condition of 900°C x 3 hours, thereafter oil-hardened from a temperature of 840°C, and then tempered under the condition of 160°C x 2 hours, is measured to determine the result as a carburized and quench hardened strain amount. In Table 2, grain boundary oxidation layer depths, quench hardening insufficient layer depths, effective hardened layer depths, core section hardnesses, rates of ferrite area, and quench hardened strain amounts of the

[0035]

[Table 2]

No.		Grain Boundary Oxidation Layer Depth (μm)	Quench Hardening Insufficient Layer Depth (μm)	Effective Hardened Layer Depth (μm)	Core Section Hardness (HV)	Rate of Ferrite Area (%)	Quench Hardened Strain Amount (%)	
							Average	Dispersion
The Present Invention Steel	1	2	0	0.58	350	38	1.32	0.10
	2	2	0	0.52	355	67	0.98	0.08
	3	1	0	0.85	382	16	1.45	0.17
	4	2	0	0.53	350	45	1.05	0.10
	5	2	0	0.55	348	39	1.27	0.15
	6	8	0	0.54	340	19	1.65	0.17
Conventional Steel	1	11	13	0.55	280	5	2.48	0.66
	2	18	15	0.53	293	7	2.60	0.70
	3	14	15	0.58	280	6	2.80	0.66
Comparative Steel	4	6	9	0.96	480	20	5.05	0.83
	5	3	1	0.65	250	76	0.90	0.08

[0036] (2) Rotary bending fatigue properties: Each test piece for rotary bending fatigue wherein a notch having 1 mm radius is provided on its parallel section (stress concentration factor a = 1.8) is prepared from a rod steel having 20 mm diameter. The test piece is subjected to carburizing and quench hardening treatment, and then, subjected to shot peening treatment (arc height: 0.6 mmA, coverage: 300%). Rotary bending fatigue test of 10^7 times is made with respect to each of the test pieces thus treated by the use of Ono type rotary bending fatigue tester to measure its rotary bending fatigue strength. In Table 3, results of rotary bending fatigue strength measured are shown.

[0037] (3) Gear fatigue properties: Each test gear having 75 mm outer diameter, 2.5 module, and 28 teeth numbers is prepared by means of cutting work from a rod steel having 90 mm diameter. The test gear is subjected to carburizing treatment and shot peening treatment under the same condition as that of the above-described rotary bending fatigue test, and then, a fatigue test is made with respect to the resulting test gear at 3000 rpm rotation number by using a power circulating type gear fatigue tester, whereby a torque value of a gear which is not broken at a repetition number of 10^7 times is determined as a dedendum strength of the gear. In Table 3, gear fatigue durability torque, and existence of chippage are shown in addition to rotary bending fatigue strength.

[0038]

[Table 3]

No.		Rotary Bending Fatigue Strength (N/mm^2)	Gear Fatigue Durability Torque (Nm)	Existence of Chippage
The Present Invention Steel	1	730	325	No
	2	735	330	No
	3	745	345	No
	4	720	320	No
	5	735	315	No
	6	735	326	No
Conventional Steel	1	686	284	Yes
	2	684	284	Yes
	3	724	313	Yes
Comparative	4	762	350	No

Steel	5	660	265	Yes

[0039] As is apparent from Tables 1 and 2, in the conventional steels Nos. 1 to 3, a rate of ferrite area, i.e. a ferrite amount is 5 to 7% which is out of the range specified in the invention to be a small amount, so that a grain boundary oxidation layer depth and quench hardening insufficient layer depth are deep, and a quench hardened strain amount is remarkable. Since the comparative steel No. 4 has a high ideal critical diameter (D_1), a quench hardened strain amount is remarkable, even if ferrite exists mixedly in austenitic structure. Furthermore, since the comparative steel No. 5 has 76% ferrite amount which is a large amount exceeding that of the specified range in the invention, so that its core section hardness is low.

[0040] On the other hand, the present invention steels Nos. 1 to 6 have remarkably reduced grain boundary oxidation layers as compared with those of conventional steels, so that no quench hardening insufficient layer is observed. Besides, these present invention steels exhibit equal to or higher carburizing effective hardened layer depth and core section hardness being carburizing and quench hardening properties than that of the conventional steels. Furthermore, since each of the present invention steels contains a dual phase structure of ferrite and martensite wherein 16 to 67% of ferrite exist, a quench hardened strain amount decreases to that about a half of a conventional steel, and in addition, there is a little dispersion from lot to lot.

[0041] As is apparent from Tables 1 and 3, chippage is observed on the surface of a gear in a low torque region in the conventional steels Nos. 1 to 3 and the comparative steel No. 5. Furthermore, since the comparative steel No. 5 has a low core section hardness, its rotary bending fatigue strength and gear fatigue property are inferior. On the other hand, the present invention steels Nos. 1 to 6 have more excellent fatigue strengths and dedendum strengths than those of the conventional steels, contain no quench hardening insufficient layer, have high tempering softening resistances by increasing a Si content, produce no chippage, and exhibit strengthened bearing strengths.

[0042]

[Advantageous effects of the Invention] As mentioned above, according to the present invention, many industrially excellent advantages can be obtained, and they are in such that steel for gears having about 50% less strain amount than that of a conventional steel

as a result of a carburizing and quench hardening treatment, and having an excellent dedendum strength can be obtained in accordance with a usual carburizing and quench hardening treatment, that the steel for gears of the invention is suitable for automobile gears to which no profile modification are applied, and that a carburized and quench hardened strain amount can be reduced in also a gear which requires profile modification after carburizing and quench hardening, i.e. the gear used in construction machineries, industrial machineries and the like, whereby it is sufficient in a small amount of profile modification, so that a decrease in working cost, and improvements in productivity can be achieved.

[Brief Description of the Drawings]

[FIG. 1] A front view showing one example of a test piece for measuring a carburized and quench hardened strain amount.

[FIG. 2] A side view of the test piece shown in FIG. 1.

[Explanation of Reference Numerals]

1 test piece

2 opening

3 circular space

[Written Amendment]

[Date of Submission] November 16, 1994

[Amendment 1]

[Name of Documents to be amended] Specification

[Item Number to be amended] 0007

[Manner of Amendment] Correction

[Contents of Amendment]

[0007] Moreover, Japanese Patent Application Laid-Open No. 5-70925 discloses a method for maintaining a cog surface area in <u>martensite</u> structure and making a cog inside area to be a fine ferrite-pearlitic structure by applying a carbonitriding treatment to a gear made of steel containing Si, Mn, Cr, Mo, V and the like within a specified range, thereafter cooling the resulting product to a temperature range equal to or less than an Ar_1 transformation point in the cog surface area, i.e. a carbonitrided area, then maintaining again the product within a range of from a temperature equal to or more than an Ar_3 transformation point in the cog surface area, i.e. the carbonitrided area to a

temperature equal to or less than the Ar_1 transformation point in the cog inside area (noncarburized area), and then quench hardening and tempering the product so treated (hereinafter referred to as "prior art 2").

[Amendment 2]

[Name of Documents to be amended] Specification

[Item Number to be amended] 0010

[Manner of Amendment] Correction

[Contents of Amendment]

[0010]

[Means for Solving the Problems] In view of the points mentioned above, the present inventors have studied eagerly for developing steel for a low strain type carburized and quench hardened gear from which a gear exhibiting a very scarce appearance of strain due to a carburizing and quench hardening treatment and having high dimensional accuracy can be obtained.

[Amendment 3]

[Name of Documents to be amended] Specification

[Item Number to be amended] 0017

[Manner of Amendment] Correction

[Contents of Amendment]

[0017] (2) Silicon (Si): Silicon is a comparatively inexpensive element being effective for elevating an Ac_3 transformation point. However, when a silicon content is less than 1.00wt.%, a silicon concentration in the vicinity of a surface layer to be combined with very small amount of oxygen in a carburizing gas at the time of a carburizing treatment is low. As a result, the above-described very small amount of oxygen invades in the depths of the steel, whereby a grain boundary oxidation layer becomes remarkably deep, and thus it results in decrease of a fatigue strength. On the other hand, when a silicon content exceeds 2.50wt.% to be excessive, SiO_2-base inclusions increase. Hence, it results in decrease of a fatigue strength, on the contrary. For this reason, a silicon content should be limited within a range of 1.00 to 2.50wt.%.

[Amendment 4]

[Name of Documents to be amended] Specification

[Item Number to be amended] 0019

[Manner of Amendment] Correction

[Contents of Amendment]

[0019] (4) Chromium (Cr): Chromium is an element effective for improving hardenability as in the case of manganese, and it is required to contain 0.10wt.% or more of chromium for achieving its function. However, since chromium has the same function for lowering the Ac_3 transformation point as that of manganese, not only no dual phase structure is obtained, but also its hardness becomes too high, resulting in deterioration of machinability, when a chromium content exceeds 1.50wt.% to be a large amount. Accordingly, a chromium content should be restricted within a range of 0.10 to 1.50wt.%.

[Amendment 5]

[Name of Documents to be amended] Specification

[Item Number to be amended] 0029

[Manner of Amendment] Correction

[Contents of Amendment]

[0029]

[Examples] In the following, the invention will be described in comparison of comparative examples to the examples of the invention wherein slabs are prepared from steels Nos. 1 to 6 of the invention each having a composition of chemical components, an Ac_3 transformation point parameter, and an ideal critical diameter (D_1) within a specified range of the invention, conventional steels Nos. 1 to 3 and comparative steels Nos. 4 and 5 each of which has at least one factor of the composition of chemical components, the Ac_3 transformation point parameter, and the ideal critical diameter (D_1) being in out of the range specified by the present invention, respectively, and as shown in Table 1.